# L-모멘트법에 의한 강우의 지역빈도분석
# Regional Frequency Analysis for Rainfall using L-Moment

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## 요약

본 연구에서는 L-모멘트법에 의한 지역화 빈도분석에 따른 설계강우량 추정에 관한 연구를 수행하였다. 제주도와 울릉도의 강우관측소를 제외한 분석에 사용된 65개 강우관측소의 강우자료 수집과 선정된 강우관측지점의 강우자료의 지속시간, 즉 1, 3, 6, 12, 24, 36, 48 및 72시간 지속의 연최대치 계열을 구성하였다. 관측지점을 대상으로 Cluster 분석을 실시한 결과 우리나라의 강우관측지점에 대한 합리적인 지역화로 5개의 지역으로 구분되었다. 지역화된 지역에 대한 지속기간별 극치강우자료의 적정분포모형 선정을 위한 6가지 분포모형의 적용하고 적용분포의 L-모멘트비를 산정하여 L-모멘트비도를 도시하고 K-S 검정에 의한 적정분포모형을 선정하였다. 선정된 적정분포는 GEV 분포이며 이 분포에 의해 강우관측치의 점빈도 및 지역빈도분석에 의한 설계강우량을 유도하였다. Monte Carlo 기법에 의해 모의발생된 강우량의 점빈도 및 지역빈도분석에 의한 설계강우량을 유도하였다. 실측치 및 모의발생치의 점빈도 및 지역빈도분석에 의한 설계강우량의 비교분석을 위해 상대제곱근오차와 상대편의오차에 의해 분석한 결과 점빈도분석에 의한 설계강우량보다 지역빈도분석에 의한 설계강우량의 사용이 적정한 것으로 나타났다.

■ 중심어 : | 강우관측소 | 연평균강우량 | 동질성검정 | L-모멘트 | GEV분포 | 몬테칼로 | 점빈도분석 | 지역빈도분석 |

## Abstract

This study was conducted to derive the optimal regionalization of the precipitation data which can be classified on the basis of climatologically and geographically homogeneous regions all over the regions except Cheju and Ulreung islands in Korea. A total of 65 rain gauges were used to regional analysis of precipitation. Annual maximum series for the consecutive durations of 1, 3, 6, 12, 24, 36, 48 and 72hr were used for various statistical analyses. K-means clustering method is used to identify homogeneous regions all over the regions. Five homogeneous regions for the precipitation were classified by the K-means clustering. Using the L-moment ratios and Kolmogorov-Smirnov test, the underlying regional probability distribution was identified to be the generalized extreme value (GEV) distribution among applied distributions. The regional and at-site parameters of the generalized extreme value distribution were estimated by the linear combination of the probability weighted moments, L-moment. The regional and at-site analysis for the design rainfall were tested by Monte Carlo simulation. Relative root-mean-square error (RRMSE), relative bias (RBIAS) and relative reduction (RR) in RRMSE were computed and compared with those resulting from at-site Monte Carlo simulation. All show that the regional analysis procedure can substantially reduce the RRMSE, RBIAS and RR in RRMSE in the prediction of design rainfall. Consequently, optimal design rainfalls following the regions and consecutive durations were derived by the regional frequency analysis.

■ keyword : | Rainfall Station | Annual Mean Rainfall | Homogeneity Test | L-moment | GEV Distribution | Monte Carlo | At-site Frequency Analysis | Regional Frequency Analysis |

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## I. Introduction

Korea has an annual mean precipitation of 1,283mm. In terms of spatial distribution, the south area has a higher annual mean precipitation (1,000-1,800mm) compared to the middle area (1,100-1,400mm). Two-thirds of Korea's annual precipitation is concentrated in the summer season (June to September). As a result, frequent localized torrential rains have damaged lives and properties every year.

Agricultural water accounts for half of the total water demand in Korea. To make its regular supply of agricultural water consistently adequate, Korea, since its foundation, has actively constructed agricultural hydraulic structures in phases. To design, operate and manage, as well as reform and maintain, these agricultural hydraulic structures, we must offer reliable design floods. To determine the cross-section of small low dams and reservoirs that are meant to generate water for agricultural and industrial purposes, construct, renovate and maintain stream levees, and to determine the capacity of drainage structures. Thus, to find out he maximum rainfall of stations, regional and at-site frequency analyses is necessary.

In these applications regional frequency analysis is known, when the hydrologic data samples are analyzed typically and observed for the same variable at a number of measuring sites within a suitably defined region. The principles of regional frequency analysis apply whenever multiple sample of similar data are available [5-6][8].

Naghavi and Schaefer [8-9] were conducted to derive the reliable design rainfalls by the development of the new techniques for the regional rainfall frequency analysis at Louisiana and Washington states in USA. It was mainly focussed to derive more reliable regional design rainfalls and diagrams using L-moments which was based on probability weighted moments as the best one among several methods for getting, the reliable design hydrologic quantity.

It was conducted to derive the optimal regionalization of the precipitation data and the regions are classified on the basis of climatologically and geographically homogeneous regions all over the regions for the estimation of the regional design rainfall The optimal regional probability distribution was identified to be the GEV distribution among applied distributions. Regional and at-site parameters of the GEV distribution were estimated by L-moment. Design rainfall using L-moment following the consecutive duration were derived and compared by the regional and at-site analyses.

## II. Method and materials

### 1. Relationship between probability weighted moments and L-moments

In this study Gumbel (GUM), Generalized Extreme Value (GEV), Generalized Logistic (GLO), Generalized Pareto (GPA), Generalized Normal (GNO) and Pearson Type 3 (PT3) distributions are used to estimate design rainfall by return period in terms of consecutive duration by regional and at-site analysis. As the method estimating parameter for these distributions, the relation between probability weighted moments and L-moments was suggested by Hosking (1986, 1990, 1996), Lee (2003), Naghavi (1995) and WMO (1989) [2-4][7][8][11]. Accordingly, formulas for estimating parameter of the applied distribution by L-moments are summarized in this paper.

### 2. Derivation of at-site and regional frequency analysis

Design rainfall for consecutive duration is induced in at-site and regional frequency analysis by Equation (1) and (2).

$$\widehat{X_T} = \hat{\xi} + \left(\frac{\hat{\alpha}}{\hat{k}}\right)\left[1-(-\ln F)^{\hat{k}}\right] \quad (1)$$

Where $T$ is the return period and $F$ is the probability of nonexceedance according to the return period.

$$\widehat{X_{T_i}} = \overline{x_i}\,\widehat{X_{T_R}} \quad (2)$$

Where $\overline{x_i}$ is mean of annual maximum rainfall for $i$ rainfall station belong to region.

Procedures for regional and at-site frequency analyses of this study are Figure 1 [4][6].

## 3. Errors for compare and analyze between at-site and regional frequency analysis

Compare and analyze the relative root-mean- square error (RRMSE) and relative bias (RBIAS) between design rainfall from observed and simulated annual maximum rainfall according to L-moment methods using regional and at-site frequency analyses.

$$RRMSE = \sqrt{\frac{1}{M}\sum_{m=1}^{M}\left\{\frac{Q_j^m - Q_j}{Q_j}\right\}^2} \quad (3)$$

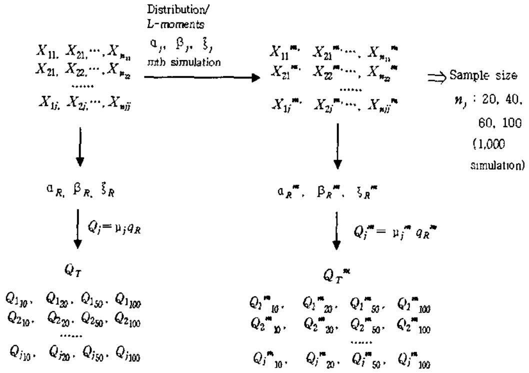
$$RBIAS = \frac{1}{M}\sum_{m=1}^{M}\left\{\frac{Q_j^m - Q_j}{Q_j}\right\} \quad (4)$$

Where, $Q_j$ and $Q_j^m$ denote design floods estimated by observed and simulated annual maximum rainfall respectively.

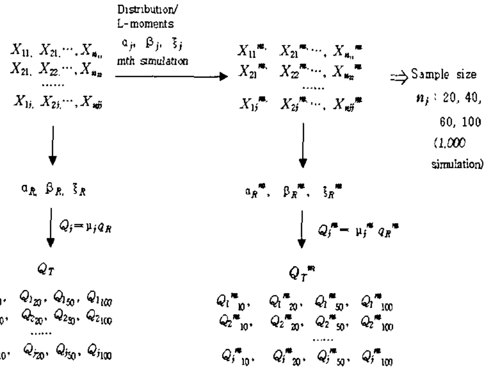
The appropriate design rainfall could be suggested for rainfall station by the frequency method either regional or at-site selected by calculating relative reduction, RR, from Equation (5) which represents relative reduction of the RRMSE calculated by regional frequency analysis compared to that by at-site frequency analysis.

$$RR = \frac{1}{n}\left\{\Sigma\frac{RRMSE_A - RRMSE_R}{RRMSE_A}\right\}\times 100 \quad (5)$$

Where $n$ is the number of meteorological stations belong to region, $RRMSE_A$ and $RRMSE_R$ are the RRMSE by at-site and regional frequency analysis.



(a) At-site frequency analysis



(b) Regional frequency analysis

Figure 1. Frequency analysis procedure by L-moments using Monte Carlo simulation

## 4. Basic hydrological data

To be able to conduct a frequency analysis of the Korea's rainfall data according to consecutive duration, it is crucial to gather reliable rainfall data, among other things. Thus, this research selected 65 rainfall stations from meteorological offices and meteorological stations under the Korea Meteorological Administration. Such stations were deemed to have highly reliable data on automatically recorded rainfalls. Observed rainfall data of different years were collected from the hydrology database of the Korea Institute of Construction Technology (KICT) in 1998.

Annual maximum series for the consecutive durations of 1, 3, 6, 12, 24, 36, 48 and 72hr according to 65 rainfall stations were constituted. We conducted to derived the optimal regionalization of the precipitation data which can be classified by the climatologically and geographically homogeneous regions all over the regions except Cheju and Ulreung islands in Korea.

## III. Results and discussion

### 1. Regionalization by K-means clustering

In the regionalization, to analyze the parameter for geographically and rainfall characters such as annual maximum rainfall, annual mean rainfall, mean rainfall of rainy season, latitude, longitude and altitude in 65 rainfall stations, K-Means clustring method is used. In the cluster analysis, We applied module in SYSTAT 8.0 developed by SPSS Inc. USA [10].

K-means clustering method is used to identify homogeneous regions all over the regions. As shown in Figure 2, five homogeneous regions for the precipitation were classified by the K-means clustering.

### 2. Selection of appropriate probability distribution

Appropriate probability distribution of annual maximum rainfall for consecutive duration in rainfall station can be selected by calculating L-moments and using an L-moment diagram [1][3]. Accordingly, L-moment diagram which is the relation between L-skewness and L-kurtosis of GUM, GEV, GLO, GPA, GNO and PT3. Distributions used in this analysis is illustrated, and after calculating L-skewness and L-kurtosis of annual maximum rainfall for consecutive duration in rainfall station are plotted on L-moment diagram, appropriate probability distribution based on this was selected. In conclusion, after plotting L-moment ratio by using L-moment on annual maximum rainfall in terms of consecutive duration by rainfall station, GEV distributions showed the appropriate probability distribution compared to other distributions.

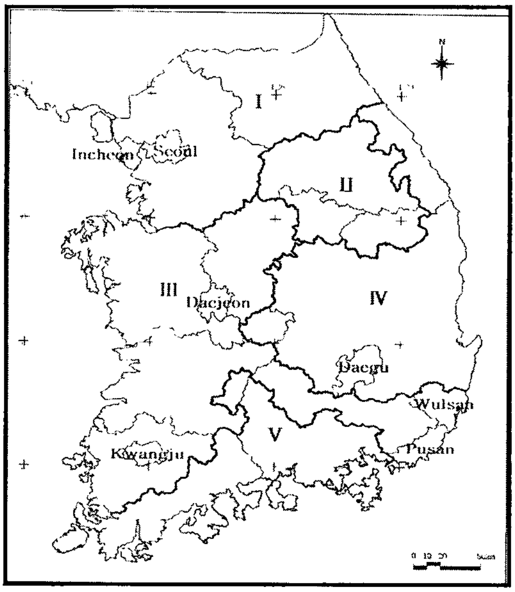


Figure 2. Five regions classified by cluster analysis

Six distributions used for selecting appropriate probability distribution of annual maximum rainfall for consecutive duration by rainfall station were calculated and determined by L-moment and then Kolmogorov-Smirnov test was conducted. Through the Kolmogorov-Smirnov test, six distributions were found to be appropriate in determining the 5 percent significance level of annual maximum rainfall in all rainfall stations.

Using the L-moment ratios and Kolmogorov-Smirnov test, the underlying regional probability distribution was identified to be the GEV distribution among applied distributions.

## 3. Estimation of the parameters of appropriate probability distribution

To induce the design rainfall for consecutive duration in rainfall stations by GEV distribution, selected as the appropriate probability distribution using regional and at-site frequency analyses, scale parameter $\alpha$, location parameter $\xi$ and shape parameter $k$ as the parameters of GEV distribution was obtained by L-moment [8].

## 4. At-site and regional frequency analysis of the observed data by appropriate probability distribution

Using the parameters of GEV distribution estimated by L-moment method, the design rainfall for consecutive duration in rainfall station is induced in at-site and regional frequency analysis by Equation (1) and (2).

## 5. Regional and at-site frequency analysis by simulated annual maximum rainfall

Hypothetical hydrologic data that have the statistical characteristics of observed data will be simulated to analyze the degree to which annual maximum rainfall series can be anticipated or calculated. The purpose in simulating the performance of the Monte Carlo technique is to find out whether the annual maximum rainfall for consecutive duration in each rainfall station is suitable to GEV distribution. [6][8] recommended the Monte Carlo technique in comparing the superiority or inferiority of more than two methods of analysis.

The sample sizes 20, 40, 60 and 100 of rainfall stations, which were derived using Monte Carlo techniques. One thousand frequency simulations were performed. In this analysis, we used simulation data on individual sample sizes by means of Monte Carlo techniques. We also derived design rainfall using regional and at-site frequency analyses. One thousand frequency simulations of annual maximum rainfall were performed according to the methods for the derivation of parameters and sample sizes of the applied rainfall stations. We used the simulated data and calculated design rainfall by means of regional and at-site frequency analyses.

## 6. Comparison and analysis of the regional and at-site frequency analyses of observed and simulated annual maximum rainfall

We estimated design rainfall for observed annual maximum rainfall and simulated annual maximum rainfall in the applied rainfall stations by means of L-moment using regional and at-site frequency analyses. We used Equation (3) and (4).

The sample size by Monte Carlo method in terms of GEV distribution, rainfall station and consecutive duration was 20, 40, 60 and 100 and simulation was conducted 1,000 times respectively. And using the simulated rainfall by GEV distribution, rainfall station, consecutive duration and sample size, design rainfall by L-moment method using regional and at-site frequency analyses was induced.

In this analysis the RRMSE and RBIAS between design rainfall by the observed rainfall and that by the simulated rainfall was drawn by GEV distribution, region, rainfall station, consecutive duration and sample size. For instance, the results of the RRMSE mean and RBIAS mean corresponding to GEV distribution of annual maximum rainfall for 24 hours consecutive duration in rainfall stations by L-moment method using regional and at-site frequency analyses are shown in Table [1] to Table [4].

In addition, using observed rainfall and the simulated rainfall by GEV distribution using regional and at-site frequency analyses, the RRMSE and RBIAS estimated by L-moment was illustrated by sample size and return period. As an example of sample, the illustrated results on annual maximum rainfall for 24 hours consecutive duration in the rainfall station of Goheung and Masan belong to V region are shown in Figure [3] and Figure [4].

And finally, the appropriate design rainfall could be suggested for rainfall station by the frequency method either regional or at-site selected by Equation (5). The result of RR between at-site frequency analysis and regional frequency analysis by sample size and return period is shown in Table [5].

As shown in Table [1] to Table [3] and Figure [3], from the findings stated above, the RRMSE by regional and at-site frequency analyses increase in proportion to the increased return period by region and decrease in proportion to the size of sample simulated. As shown in the result of Table [4], the RBIAS by regional frequency analysis was smaller then at-site frequency analysis and this result became smaller when the size of sample became increased.

In the result of Table [5] showing relatively reduced ratio of the RRMSE by regional frequency analysis compared to that by at-site frequency analysis, as the return period became longer, the increase in the RRMSE by regional frequency analysis in the RR is bigger than that by at-site frequency analysis. This tendency becomes more noticeable in proportion to the length of return period and this represents that the design rainfall by regional frequency analysis is more reliable than that by at-site frequency analysis.

Synthetically, the design rainfall induced by regional frequency analysis for overall consecutive duration and in rainfall stations is determined to be appropriate.

To test the result the designed rainfall for 24 and 72 hours consecutive duration in regions induced by regional frequency analysis is illustrated in Normal probability paper by Gringorten plotting position method. For instance, the illustrated result on annual maximum rainfall for 24 and 72 hours consecutive duration in five regions is provided in Figure [4].

## IV. Conclusions

It is matter of common knowledge to give impetus to the water resources development to cope with increasing demand and supply for the water utilization project including agricultural, living and industrial water owing to the economic and civilization development in recent years. Regional design rainfall is necessary for the design of the dam, reservoir, levee and drainage facilities for the development of various kinds of essential waters including agricultural water. For the estimation of the regional design rainfall, classification of the climatologically and geographically homogeneous regions should be preceded preferentially.

Table 1. RRMSE of the simulated quantile following the sample size and region for 24-hr consecutive duration of GEV distribution by at-site frequency analysis

| Simulated sample size | Region | Return period (year) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $Q_{5}$ | $Q_{10}$ | $Q_{20}$ | $Q_{50}$ | $Q_{100}$ | $Q_{200}$ | $Q_{500}$ |
| 20 | I | 0.1253 | 0.1532 | 0.1951 | 0.2713 | 0.3457 | 0.4377 | 0.5944 |
| | II | 0.1098 | 0.1297 | 0.1615 | 0.2211 | 0.2793 | 0.3503 | 0.4675 |
| | III | 0.1050 | 0.1258 | 0.1589 | 0.2209 | 0.2816 | 0.3561 | 0.4812 |
| | IV | 0.1047 | 0.1254 | 0.1578 | 0.2175 | 0.2759 | 0.3471 | 0.4664 |
| | V | 0.1136 | 0.1372 | 0.1738 | 0.2415 | 0.3083 | 0.3909 | 0.5317 |
| 40 | I | 0.0880 | 0.1095 | 0.1428 | 0.2036 | 0.2619 | 0.3324 | 0.4483 |
| | II | 0.0767 | 0.0911 | 0.1153 | 0.1604 | 0.2036 | 0.2548 | 0.3364 |
| | III | 0.0740 | 0.0896 | 0.1149 | 0.1615 | 0.2061 | 0.2591 | 0.3445 |
| | IV | 0.0738 | 0.0895 | 0.1150 | 0.1621 | 0.2073 | 0.2616 | 0.3500 |
| | V | 0.0795 | 0.0966 | 0.1239 | 0.1738 | 0.2214 | 0.2777 | 0.3678 |
| 60 | I | 0.0723 | 0.0906 | 0.1193 | 0.1710 | 0.2200 | 0.2778 | 0.3705 |
| | II | 0.0628 | 0.0753 | 0.0961 | 0.1343 | 0.1701 | 0.2117 | 0.2760 |
| | III | 0.0605 | 0.0735 | 0.0947 | 0.1337 | 0.1705 | 0.2134 | 0.2806 |
| | IV | 0.0605 | 0.0735 | 0.0948 | 0.1340 | 0.1712 | 0.2153 | 0.2858 |
| | V | 0.0653 | 0.0801 | 0.1035 | 0.1459 | 0.1856 | 0.2320 | 0.3045 |
| 100 | I | 0.0561 | 0.0706 | 0.0932 | 0.1337 | 0.1713 | 0.2147 | 0.2820 |
| | II | 0.0495 | 0.0592 | 0.0753 | 0.1046 | 0.1316 | 0.1623 | 0.2087 |
| | III | 0.0471 | 0.0575 | 0.0747 | 0.1061 | 0.1352 | 0.1689 | 0.2205 |
| | IV | 0.0470 | 0.0573 | 0.0743 | 0.1052 | 0.1340 | 0.1673 | 0.2187 |
| | V | 0.0507 | 0.0624 | 0.0813 | 0.1155 | 0.1472 | 0.1838 | 0.2402 |

Table 2. RBIAS of the simulated quantile following the sample size and region for 24-hr consecutive duration of GEV distribution by at-site frequency analysis

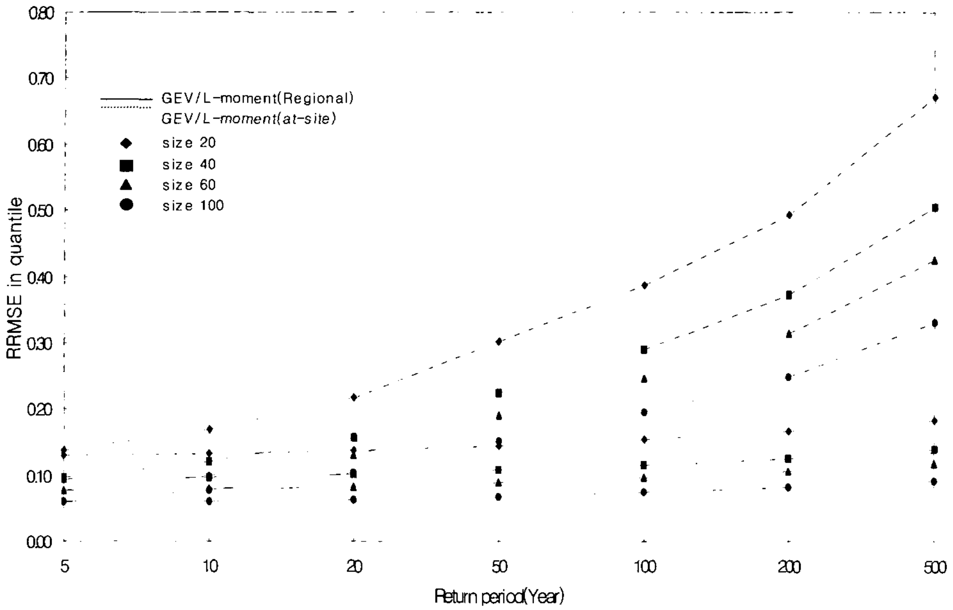
| Simulated sample size | Region | Return period (year) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $Q_{5}$ | $Q_{10}$ | $Q_{20}$ | $Q_{50}$ | $Q_{100}$ | $Q_{200}$ | $Q_{500}$ |
| 20 | I | 0.0007 | -0.0053 | -0.0089 | -0.0076 | -0.0007 | 0.0126 | 0.0420 |
| | II | -0.0001 | -0.0006 | 0.0014 | 0.0091 | 0.0196 | 0.0349 | 0.0637 |
| | III | 0.0004 | -0.0003 | 0.0010 | 0.0074 | 000169 | 0.0313 | 0.0593 |
| | IV | 0.0012 | 0.0001 | 0.0010 | 0.0066 | 0.0153 | 0.0286 | 0.0548 |
| | V | 0.0004 | -0.0018 | -0.0015 | 0.0046 | 0.0147 | 0.0305 | 0.0620 |
| 40 | I | -0.0013 | -0.0044 | -0.0056 | -0.0030 | 0.0032 | 0.0136 | 0.0353 |
| | II | -0.0002 | -0.0002 | 0.0015 | 0.0071 | 0.0143 | 0.0245 | 0.0433 |
| | III | -0.0002 | -0.0006 | 0.0003 | 0.0044 | 0.0104 | 0.0194 | 0.0366 |
| | IV | -0.0004 | -0.0009 | 0.0001 | 0.0045 | 0.0109 | 0.0203 | 0.0385 |
| | V | -0.0010 | -0.0024 | -0.0023 | 0.0013 | 0.0073 | 0.0167 | 0.0351 |
| 60 | I | -0.0010 | -0.0034 | -0.0045 | -0.0028 | 0.0014 | 0.0088 | 0.0242 |
| | II | -0.0009 | -0.0009 | 0.0004 | 0.0046 | 0.0100 | 0.0175 | 0.0312 |
| | III | -0.0002 | -0.0006 | -0.0001 | 0.0028 | 0.0071 | 0.0136 | 0.0261 |
| | IV | -0.0002 | -0.0006 | 0.0001 | 0.0032 | 0.0076 | 0.0144 | 0.0272 |
| | V | -0.0008 | -0.0019 | -0.0018 | 0.0008 | 0.0051 | 0.0118 | 0.0249 |
| 100 | I | -0.0003 | -0.0018 | -0.0024 | -0.0012 | 0.0016 | 0.0064 | 0.0162 |
| | II | -0.0005 | -0.0008 | -0.0003 | 0.0019 | 0.0048 | 0.0089 | 0.0167 |
| | III | -0.0001 | -0.0004 | 0.0000 | 0.0020 | 0.0049 | 0.0093 | 0.0176 |
| | IV | -0.0001 | -0.0002 | 0.0003 | 0.0024 | 0.0055 | 0.0100 | 0.0185 |
| | V | -0.0004 | -0.0011 | -0.0010 | 0.0008 | 0.0037 | 0.0083 | 0.0171 |

Table 3. RRMSE of the simulated quantile following the sample size and region for 24-hr consecutive duration of GEV distribution by regional frequency analysis

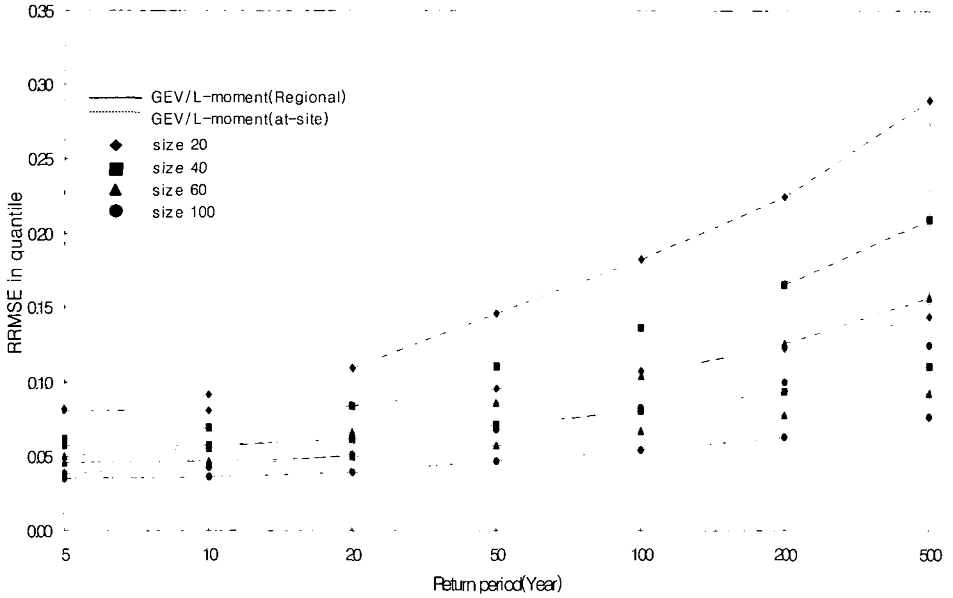
| Simulated sample size | Region | Return period (year) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $Q_5$ | $Q_{10}$ | $Q_{20}$ | $Q_{50}$ | $Q_{100}$ | $Q_{200}$ | $Q_{500}$ |
| 20 | I | 0.1236 | 0.1251 | 0.1295 | 0.1409 | 0.1537 | 0.1694 | 0.1936 |
| | II | 0.1043 | 0.1087 | 0.1162 | 0.1312 | 0.1463 | 0.1643 | 0.1921 |
| | III | 0.1021 | 0.1032 | 0.1053 | 0.1104 | 0.1160 | 0.1231 | 0.1345 |
| | IV | 0.1033 | 0.1053 | 0.1089 | 0.1167 | 0.1251 | 0.1353 | 0.1512 |
| | V | 0.1094 | 0.1107 | 0.1145 | 0.1239 | 0.1342 | 0.1468 | 0.1662 |
| 40 | I | 0.0874 | 0.0893 | 0.0936 | 0.1039 | 0.1151 | 0.1287 | 0.1496 |
| | II | 0.0729 | 0.0762 | 0.0825 | 0.0956 | 0.1089 | 0.1249 | 0.1496 |
| | III | 0.0724 | 0.0733 | 0.0752 | 0.0796 | 0.0843 | 0.0901 | 0.0994 |
| | IV | 0.0727 | 0.0746 | 0.0778 | 0.0846 | 0.0917 | 0.1003 | 0.1138 |
| | V | 0.0779 | 0.0793 | 0.0828 | 0.0910 | 0.0998 | 0.1104 | 0.1266 |
| 60 | I | 0.0709 | 0.0727 | 0.0767 | 0.0858 | 0.0953 | 0.1068 | 0.1244 |
| | II | 0.0593 | 0.0623 | 0.0678 | 0.0791 | 0.0904 | 0.1039 | 0.1245 |
| | III | 0.0591 | 0.0599 | 0.0616 | 0.0654 | 0.0694 | 0.0744 | 0.0822 |
| | IV | 0.0592 | 0.0608 | 0.0637 | 0.0696 | 0.0756 | 0.0830 | 0.0944 |
| | V | 0.0630 | 0.0644 | 0.0677 | 0.0753 | 0.0833 | 0.0928 | 0.1073 |
| 100 | I | 0.0547 | 0.0561 | 0.0590 | 0.0657 | 0.0729 | 0.0816 | 0.0951 |
| | II | 0.0464 | 0.0483 | 0.0520 | 0.0602 | 0.0686 | 0.0789 | 0.0947 |
| | III | 0.0456 | 0.0463 | 0.0477 | 0.0508 | 0.0541 | 0.0581 | 0.0644 |
| | IV | 0.0462 | 0.0476 | 0.0498 | 0.0543 | 0.0590 | 0.0646 | 0.0735 |
| | V | 0.0489 | 0.0499 | 0.0527 | 0.0591 | 0.0658 | 0.0738 | 0.0860 |

Table 4. RBIAS of the simulated quantile following the sample size and region for 24-hr consecutive duration of GEV distribution by regional frequency analysis

| Simulated sample size | Region | Return period (year) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $Q_5$ | $Q_{10}$ | $Q_{20}$ | $Q_{50}$ | $Q_{100}$ | $Q_{200}$ | $Q_{500}$ |
| 20 | I | 0.0122 | 0.0018 | -0.0111 | -0.0306 | -0.0463 | -0.0625 | -0.0842 |
| | II | 0.0016 | 0.0019 | 0.0027 | 0.0048 | 0.0072 | 0.0103 | 0.0158 |
| | III | 0.0055 | 0.0014 | -0.0041 | -0.0125 | -0.0194 | -0.0265 | -0.0362 |
| | IV | 0.0166 | 0.0095 | 0.0053 | -0.0022 | -0.0086 | -0.0155 | -0.0249 |
| | V | 0.0080 | -0.0009 | -0.0115 | -0.0271 | -0.0396 | -0.0524 | -0.0695 |
| 40 | I | 0.0078 | 0.0019 | -0.0056 | -0.0168 | -0.0259 | -0.0353 | -0.0480 |
| | II | -0.0017 | 0.0001 | 0.0029 | 0.0080 | 0.0128 | 0.0184 | 0.0270 |
| | III | 0.0035 | 0.0009 | -0.0024 | -0.0072 | -0.0111 | -0.0152 | -0.0206 |
| | IV | 0.0084 | 0.0081 | 0.0062 | 0.0025 | -0.0009 | -0.0046 | -0.0097 |
| | V | 0.0056 | -0.0006 | -0.0079 | -0.0185 | -0.0271 | -0.0358 | -0.0476 |
| 60 | I | 0.0059 | 0.0012 | -0.0046 | -0.0135 | -0.0208 | -0.0284 | -0.0386 |
| | II | -0.0031 | -0.0014 | 0.0012 | 0.0059 | 0.0103 | 0.0154 | 0.0230 |
| | III | 0.0021 | -0.0003 | -0.0031 | -0.0073 | -0.0106 | -0.0141 | -0.0188 |
| | IV | 0.0073 | 0.0073 | 0.0060 | 0.0031 | 0.0004 | -0.0026 | -0.0069 |
| | V | 0.0042 | -0.0015 | -0.0082 | -0.0178 | -0.0256 | -0.0336 | -0.0444 |
| 100 | I | 0.0041 | 0.0005 | -0.0040 | -0.0110 | -0.0167 | -0.0227 | -0.0310 |
| | II | -0.0036 | -0.0019 | 0.0008 | 0.0055 | 0.0098 | 0.0146 | 0.0218 |
| | III | 0.0012 | -0.0008 | -0.0031 | -0.0063 | -0.0090 | -0.0117 | -0.0154 |
| | IV | 0.0063 | 0.0066 | 0.0057 | 0.0035 | 0.0013 | -0.0012 | -0.0049 |
| | V | 0.0028 | -0.0024 | -0.0085 | -0.0174 | -0.0245 | -0.0319 | -0.0420 |



(a) Goheung

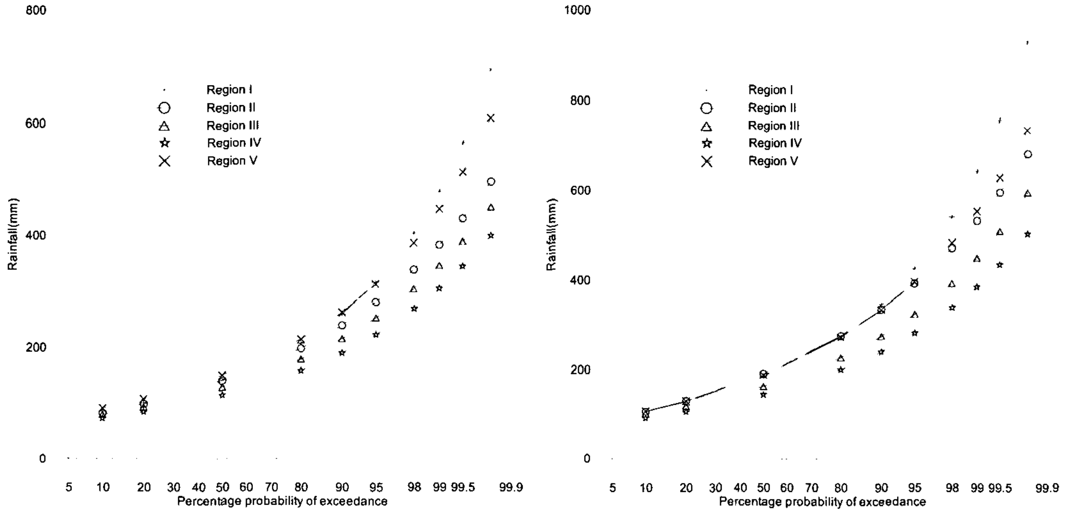


(b) Masan

Figure 3. Comparison of regional and at-site procedures for 24-hr consecutive duration in region V

Table 5. Relative (%) in RRMSE by region and at-site for 24-hr consecutive duration of GEV distribution

| Simulated sample size | Region | Return period (year) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $Q_5$ | $Q_{10}$ | $Q_{20}$ | $Q_{50}$ | $Q_{100}$ | $Q_{200}$ | $Q_{500}$ |
| 20 | I | 1.58 | 18.40 | 33.46 | 47.66 | 54.99 | 60.59 | 66.56 |
| | II | 5.04 | 15.90 | 27.45 | 39.83 | 46.69 | 52.04 | 57.68 |
| | III | 3.44 | 17.66 | 32.52 | 48.20 | 56.70 | 63.04 | 69.26 |
| | IV | 3.07 | 16.83 | 30.87 | 45.35 | 53.16 | 59.05 | 65.04 |
| | V | 3.83 | 18.49 | 32.50 | 46.39 | 53.72 | 59.29 | 65.05 |
| 40 | I | 1.12 | 18.72 | 34.35 | 48.45 | 55.30 | 60.29 | 65.33 |
| | II | 4.97 | 16.02 | 27.65 | 39.14 | 44.97 | 49.16 | 53.32 |
| | III | 3.08 | 17.97 | 33.09 | 48.32 | 56.19 | 61.84 | 67.14 |
| | IV | 2.84 | 16.75 | 31.08 | 45.30 | 52.51 | 57.67 | 62.57 |
| | V | 2.49 | 17.37 | 31.70 | 45.32 | 52.09 | 56.96 | 61.73 |
| 60 | I | 2.45 | 20.00 | 35.58 | 49.30 | 55.84 | 60.47 | 65.05 |
| | II | 5.47 | 16.85 | 28.57 | 39.68 | 45.07 | 48.79 | 52.31 |
| | III | 2.98 | 17.82 | 33.04 | 48.23 | 55.91 | 61.31 | 66.28 |
| | IV | 3.72 | 17.42 | 31.63 | 45.54 | 52.44 | 57.28 | 61.76 |
| | V | 3.96 | 18.95 | 32.95 | 45.72 | 51.83 | 56.11 | 60.19 |
| 100 | I | 2.87 | 20.65 | 36.41 | 50.12 | 56.41 | 60.72 | 64.70 |
| | II | 6.12 | 17.88 | 29.86 | 40.85 | 45.92 | 49.17 | 51.90 |
| | III | 3.75 | 18.55 | 33.55 | 48.26 | 55.61 | 60.72 | 65.30 |
| | IV | 2.92 | 19.96 | 31.51 | 45.47 | 52.20 | 56.77 | 60.77 |
| | V | 3.87 | 19.13 | 33.12 | 45.45 | 51.10 | 54.92 | 58.39 |



(a) 24-hr consecutive duration (b) 72-hr consecutive duration

Figure 4. Comparison of the regional quantiles for the consecutive duration of 24 and 72-hr of five regions

This study was mainly conducted to derive the optimal regionalization of the precipitation data which can be classified by the climatologically and geographically homogeneous regions all over the regions except Cheju and Ulreung islands in Korea. A total of 65 rain gauges were used to regional analysis of precipitation. Annual maximum series for the consecutive durations of 1, 3, 6, 12, 24, 36, 48 and 72hr were used for various statistical analyses. K-means Clustering method is used to identify homogeneous regions all over the regions. Five homogeneous regions for the precipitation were classified by the K-means clustering.

This study was conducted to derive the regional design rainfall by the regional frequency analysis based on the regionalization of the precipitation suggested by this project. Using the L-moment ratios and Kolmogorov-Smirnov test, the underlying regional probability distribution was identified to be the generalized extreme value distribution among applied distributions. The regional and at-site parameters of the generalized extreme value distribution were estimated by the linear combination of the probability weighted moments, L-moment.

The regional and at-site analysis for the design rainfall were tested by Monte Carlo simulation. RRMSE, RBIAS and RR in RRMSE were computed and compared with those resulting from at-site Monte Carlo simulation. All show that the regional analysis procedure can substantially reduce the RRMSE, RBIA and RR in RRMSE in the prediction of design rainfall.

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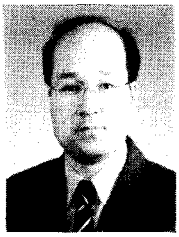

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